2011

A Model-Based Framework for NPD in a Highly Regulated Environment

Lourdes A. Medina, *University of Puerto Rico, Mayaguez*
Gül E. Kremer, *Iowa State University*
Richard A. Wysk, *Penn State University*

Proceedings of the 2011 Industrial Engineering Research Conference
T. Doolen and E. Van Aken, eds.

A Model-Based Framework for NPD in a Highly Regulated Environment

Lourdes A. Medina[1], Gül E. Okudan Kremer[2, 1]
[1]Department of Industrial and Manufacturing Engineering
[2]School of Engineering Design
Pennsylvania State University
University Park, PA 16802, U.S.A.

Richard A. Wysk
Industrial and Systems Engineering
North Carolina State University
Raleigh, NC 27695, U.S.A.

Abstract

The completeness of the New Product Development (NPD) process is a critical factor for the success of new products. Empirical research demonstrates a significant correlation between the number of stages followed in the development process and the success of new medical devices. At the same time, the experience of the development team impacts the time-to-market of new products, which correlates directly to success. Medical device development is a very complex area in NPD due to the complex nature of these products, multiple stakeholder groups, and the regulatory processes involved. While detailed descriptions of different components of the NPD process exist in literature, they in general lack in comprehensiveness. To fill this void, the proposed model in this paper provides a complete framework for inexperienced developers to follow in medical device development endeavors. Regulations play a significant role in the development, considering the regulatory pathways at early stages of the development and having to comply with design controls. The model is divided into five components: product definition, design, risk management, production planning, market introduction and post-launch and medical device records. The flow of the process is demonstrated using an example of total hip replacements.

Keywords
New Product Development, Medical Devices; Conceptual Model

1. Introduction
Models are broadly used as an aid to develop a better understanding of systems and processes. Numerous process models have been proposed for the design and development of generic products. A comparative analysis of relevant literature summarized the normative design process in five steps: (1) needs assessment/problem definition; (2) conceptualization; (3) preliminary design and evaluation; (4) detailed design and testing; and (5) production [1]. The medical device development process is very similar to this framework, but with additional details within each process step to incorporate the regulation requirements.

Pietzsch et al. [2] define the stage-gate development process of medical devices through the analysis of best practices and in-depth interviews of experts involved in the development, commercialization and regulation processes. Alexander and Clarkson's [3] approach focuses on the validation aspect of medical devices, by providing a model of design for validation (DFV). Panescu [4] reviews the process for designing medical devices, providing a general description of the process and addressing issues of intellectual property and the FDA regulation.

Aitchison et al. [5] discuss the development process for the specific case of implantable orthopedic medical devices; however, the process they describe applies in general to any medical device and is consistent with other reviews in the literature. Das and Almonor [6] provide an attribute-driven concurrent engineering approach for the development

of medical devices. Their approach includes customer, functional and regulatory attributes. Hill [7] also defines the design phases for medical devices in general but with a low level of detail.

In contrast to previous literature, the defined model here provides a more comprehensive framework for the development process of medical devices. The completeness of the New Product Development (NPD) process is a critical factor for the success of new medical devices in the market, as empirical research demonstrates a significant correlation between the number of stages followed in the development process and the success of new medical devices [8]. At the same time, the experience of the development team impacts the time-to-market of new medical devices, which is also related to success [9]. The model presented provides a detailed structure of all the process components and serves as a template that designers can follow throughout the medical device development process.

2. The Model

The literature reviewed serves as the foundation to understand how medical device development is addressed from multiple perspectives, but also illustrates the need for a more comprehensive model of the process. This has motivated the development of a conceptual model for the medical device development process. The model is the result of a documentation analysis where more than a hundred and thirty documents were reviewed. The development of the model included verifications of source credibility, the model completeness, terminology, and redundancy. The model is developed using the Unified Modeling Language's (UML) relationships. UML is a well-known general-purpose modeling language. Cadifra UML Editor 1.3 is the software used to build the model for this work. The different UML relationships symbols used for this work along with their meanings are summarized in Table 1. Using well-founded relationships, the model provides additional information and exhibits a higher degree of detail in comparison to other graphical representations in the literature, e.g. Alexander and Clarkson's [3], Aitchison et al. [5], FDA [10].

Table 1: Model relationships

Relationships (UML notation)	Meaning
Generalization	Inheritance, "is a" relationship
Association	related with a verb
Aggregation	"has a" relationship
Composition	being part of a whole where the part does not exist if there is no whole
Dependency	demonstrates that a class depends from other

The model describes the medical device development and introduction processes. These processes are summarized at a higher level as: (1) product definition process, (2) design process, (3) risk management process, (4) production planning process, and (5) market introduction and post launch process. The product definition process (Figure 1) is very broad, incorporating different types of analyses, such as competencies analysis, market analysis and financial analysis, to come up with a product proposal. Conversely, the components of the design process (Figure 2) are very specific and mostly defined with FDA's terminology (given that this process is subject to the design controls from the good manufacturing practices/quality systems (GMP/QS) regulations). The risk management process (Figure 3) includes four fundamental steps (identification, analysis, control and monitoring) to follow in parallel with the design process; see Section 3 for an example. The production planning process (Figure 4) is focused on the validation of the manufacturing processes. Finally, the market introduction and post launch process (Figure 5) is executed, with simultaneous steps to the design process. A variety of records (Figure 6) are kept as necessary documentation for multiple purposes. Finally, Figure 7 illustrates the complete model as a compilation of Figures 1 through 6, along with additional relationships that are applicable to components between the different processes. Examples of the analysis involved at specific components of the model are included in Section 3.

The model includes different levels of granularity, which follow a hierarchical approach to differentiate among these levels. This hierarchical approach is a result of the review process for usability, where the model structure was re-designed to follow a left to right logic to be consistent with the form we read and write. Considering the diagrams by cluster, higher level (less granular) components are at the left side and lower level (higher granularity) components are at the right side. Likewise, the granularity may increase downward for some of the components at the right side.

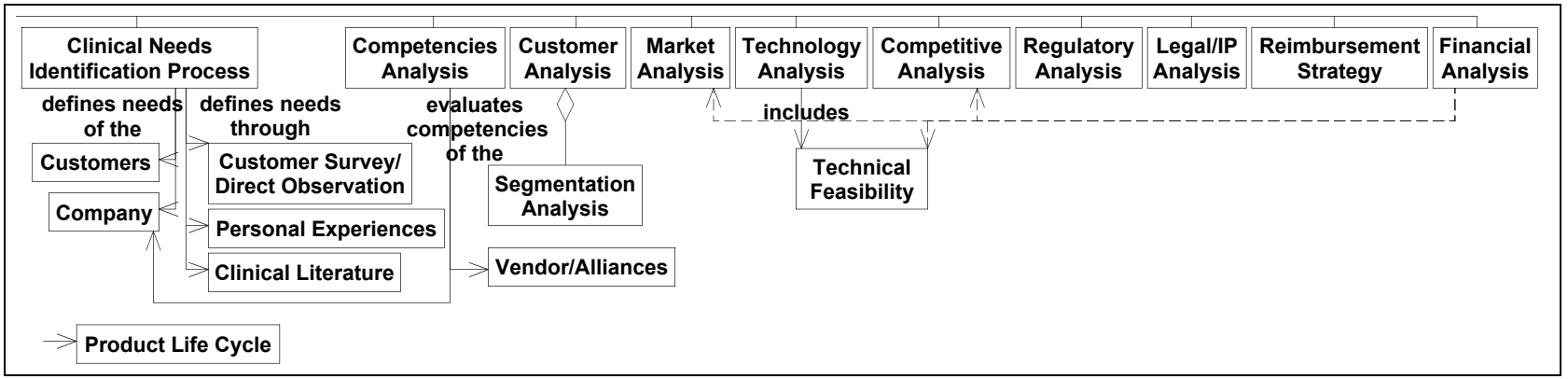

Figure 1: Product definition process

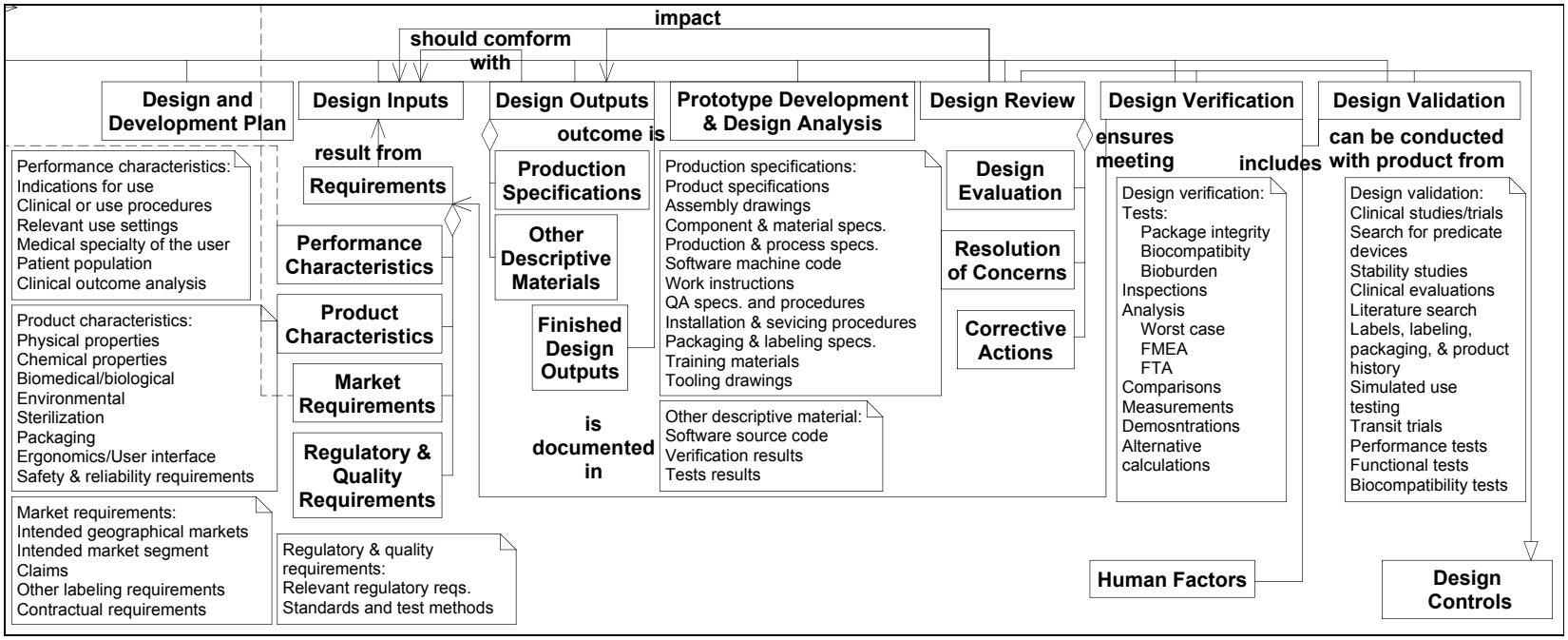

Figure 2: Design process

Figure 3: Risk management processes

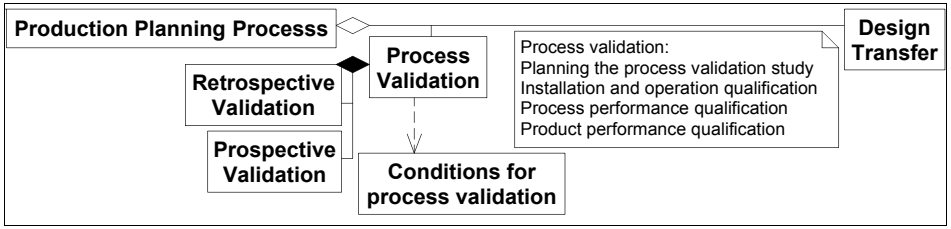

Figure 4: Production planning processes

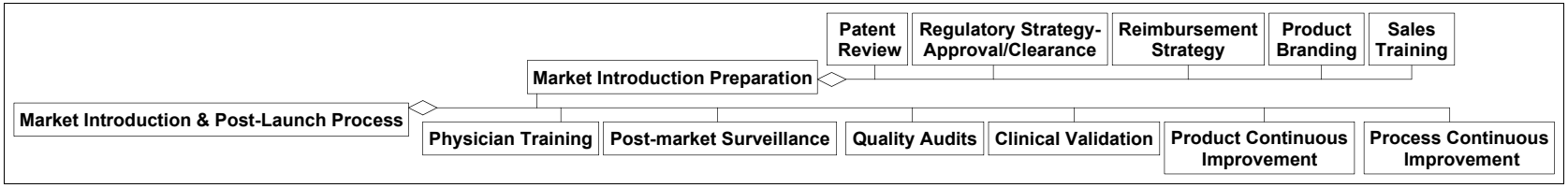

Figure 5: Market introduction & post-launch process

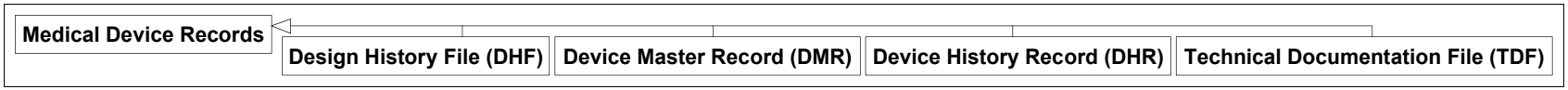

Figure 6: Medical device records

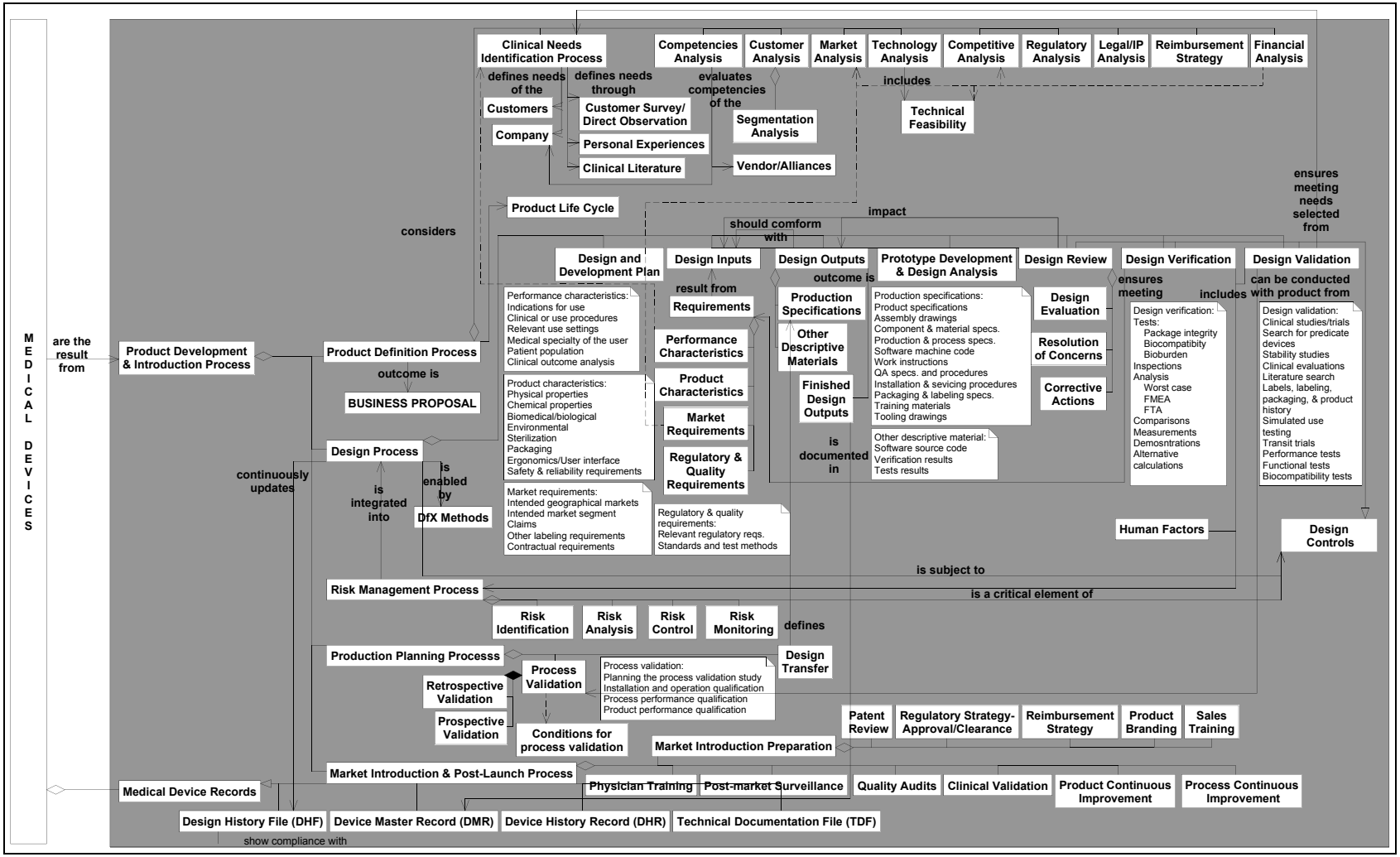

Figure 7: Medical device development and introduction processes

The overall model granularity is appropriate for designers to understand and further use the model in a particular medical device development. The model's highest level of granularity includes the description of specific requirements through the addition of notes in the model, e.g. Figure 2. A more detailed approach (from the example) would involve specifying particular physical properties; however, the physical properties may be dependent on the specific medical device application.

In summary, the proposed model defines the requirements for a complete development process, completeness that has been identified in the literature, e.g. Rochford and Rudelius [8], as a critical factor for success. At the same time, the model becomes an important reference for inexperience designers to follow; as empirical evidence demonstrates that the experience of the development team impacts the time-to-market of new medical devices [9]. The utility of the model is further shown in the following section, with examples of the analysis performed for specific components of the model.

3. Scenario

The model proposed in this paper is comprehensive, but generalized enough to be applied for any medical device development. For most medical devices every component of the development process should be addressed. Some exemptions to this may include the development of devices for humanitarian purposes, where the reimbursement strategy and financial analysis play a smaller role (or no role) in the development.

This section shows how specific components of the model apply to the development of a new total hip replacement system for skeletally matured patients with non-inflammatory degenerative joint disease. For the purpose of this example the MRA classification (FDA's product code) is selected, as the applicable classification for the device to develop. The MRA classification is the generic type for medical devices that are: prosthesis, hip, semi-constrained, metal/ceramic/ceramic/metal, cemented or uncemented.

For this discussion, two processes are highlighted: the product definition process and the risk management process. Both of these processes are crucial for the success of any medical device. The product definition process, summarized in a business proposal, includes multiples analyses with the ultimate goal of selecting to develop a device that will solve a clinical need, is feasible to develop and will generate the desired outcomes. The risk management process is integrated into the design process, followed throughout the different states of the design process. The safety of any medical device is critical, and especially for implantable devices.

Within the scenario, the decision to develop a new total hip replacement system should come from careful analyses during the product definition process. Figure 8, illustrates the product definition process and examples of some of the considerations for the clinical need identification, competitive analysis and reimbursement strategy. For the clinical need identification process, there is a need to develop orthopedic devices for the multiple joints and areas of the spine. Clinical literature can be used to justify these needs and the specific selection of a particular development. Further, the selected need should be aligned with the customer's and company's needs. Customer considerations should include that females have a higher rate for total, partial and revision hip replacements and that the higher percent of patients is between the ages of 25-64 Zhan et al. [11]. Other studies show that the peak of hip replacements is at the ages 65-79 [12]. For the competitive analysis, direct and indirect competitions are considered. Figure 8 illustrates all the devices in the MRA classification, which are the most direct competition for this scenario. However, there are many other hip-related devices to be considered, coded under other classification that satisfy the same clinical need. For the reimbursement strategy, a realistic method for return on investment must be specified. The figure includes statistics on how different insurances have reimbursed different kind of procedures in the past to use as a reference, e.g. Medicare, Medicaid, Private, and Uninsured.

The risk management process is crucial for total hip replacement systems, given that these devices represent high risk for being used inside the body. In particular, there is high risk of device related infections. Figure 9 illustrates the components of the risk management process and an example of what is expected from the risk analysis. The device should be analyzed to define all the potential failure modes, the effect of failure and the cause of failure. The failures are characterized in terms of occurrence (O), severity (S) and ease of detection (D) in order to come up with a risk priority number (RPN). Further, actions to reduce or eliminate the risk should be specified.

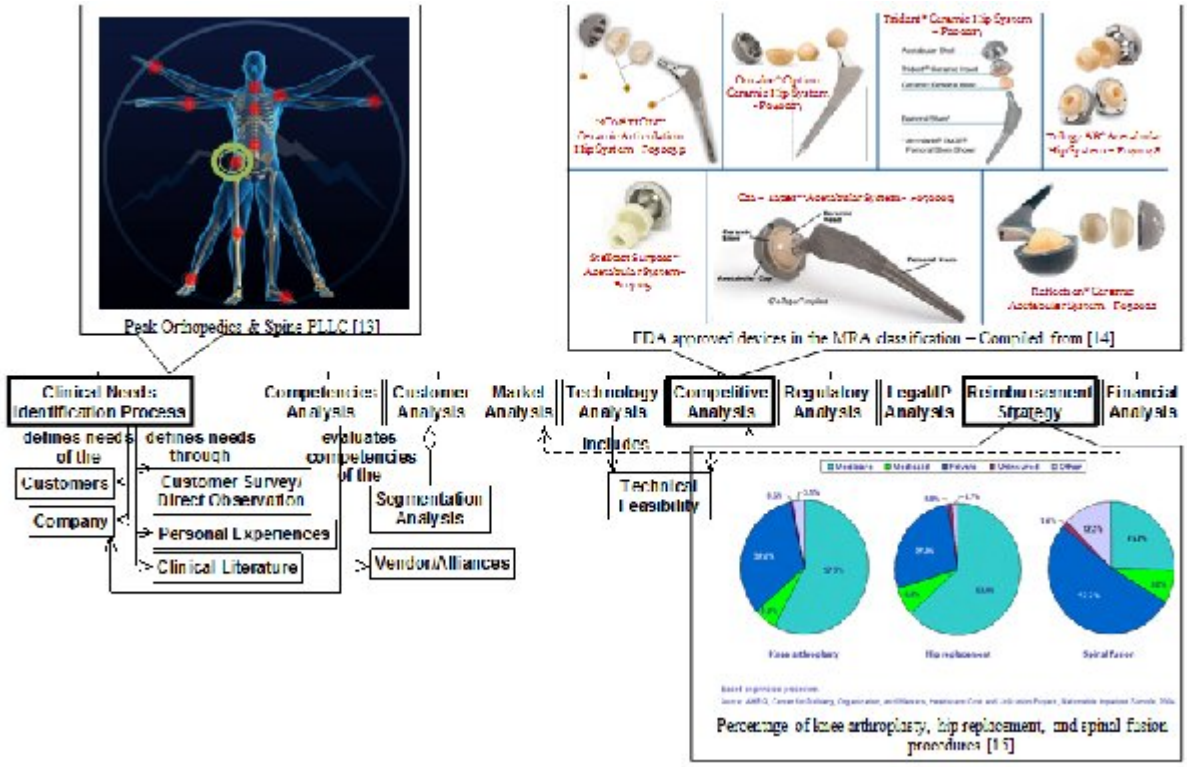

Figure 8: Scenario – components of the product definition process (Examples from [13-15])

Partial Results of a Risk Analysis for the Swanson Wrist Implant. The Occurrence (O), Severity (S) and Detection (D) are Rated on a Scale of 1 to 10 and Multiplied Together to Give a Risk Priority Number (RPN) [5]

Possible Failure Mode	Effect of Failure	Cause of Failure	O	S	D	RPN	Action to Reduce or Eliminate Risk
Breaks	Device does not function as intended	Fatigue failure	10	6	5	300	
		Tears from sharp edges of bone	10	6	5	300	Grommets have been designed for use with the Swanson wrist implant
		Damaged during implantation using sharp instruments	2	6	5	60	Use of correct instrumentation, trained hand surgeon, adequate and clear instructions for use
		Incorrect implantation technique	2	6	5	60	Trained hand surgeon; adequate instructions for use
Wear particles of silicone	Silicone synovitis	Implant rubbing against bone	8	6	7	336	

Figure 9: Scenario – components of the risk management process

Other parts of the processes to emphasize due to the FDA regulations are the clinical trials, as part of the validation process, and the documentation. Note that clinical trials may not be necessary if the proposed device is a compound of FDA approved components where clinical evidence can be addressed. Only two of the seven devices analyzed in the MRA classification conducted clinical trials. However, documentation is critical for any medical device development. This includes maintaining records of the design changes during the design process.

4. Conclusion and Future Work

The development of medical devices is a complex problem from initial conception to final implementation and monitoring, through which the regulated nature of medical devices plays a significant role. Consistent with general product development, an important part of medical device development involves satisfying customers' and company's needs. However, contrary to commercially minimally regulated products, the development of medical devices is performed under regulations/requirements, which provide additional constraints for the development, manufacturing, marketing and continuous improvement of medical devices. This requires the early consideration of regulatory pathways and the incorporation of design controls.

This paper presents a conceptual model as a more comprehensive visualization tool that designers can use proactively during the development process to handle the complexities of medical device development and identify strategies for a more efficient development process. This further enhances product success through the completeness of the model and the framework for inexperience developers. Future directions of this research include further developing this model for more completeness by incorporating components of the medical device environment.

References

1. Ogot, M., and Okudan-Kremer, G., 2004, Engineering Design: A Practical Guide. Victoria, Canada: Trafford Publishing.
2. Pietzsch, J.B., Shluzas, L.A., Pate-Cornell, M.E., Yock, P.G., and Linehan, J.H., 2009, "State-gate process for the development of medical devices," Journal of Medical Devices, 3, 1-15.
3. Alexander, K., and Clarkson, P.J., 2002, "A validation model for the medical devices industry," Journal of Engineering Design, 13 (3), 197 – 204.
4. Panescu, D., 2009, "Medical device development," 31st Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBS), Minneapolis, Minnesota, 5591-5594.
5. Aitchison G.A., Hukins, D.W.L., Parry, J.J., Shepherd, D.E.T., and Trotman, S.G., 2009, "A review of the design process for implantable orthopedic medical devices," The Open Biomedical Engineering Journal, 3, 21-17.
6. Das, S.K., and Almonor, J.B., 2000, "A concurrent engineering approach for the development of medical devices," International Journal of Computer Integrated Manufacturing, 13 (2), 139-147.
7. Hill, A.V., and Sawaya III, W.J., 2004, "Production planning for medical devices with an uncertain regulatory approval date," IIE Transactions, 36, 307-317.
8. Rochford, L., and Rudelius, W., 1997, "New product development processes: Stages and succeses in the medical products industry," Industrial Marketing Management, 26, 76-84.
9. Lucke L.E., Mickelson, A., and Anderson, D., 2009, "Proving experience speeds medical device time to market," 31st Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBS), Minneapolis, Minnesota, 7057 – 7060.
10. FDA, 1997, Design control guidance for medical device manufacturers, CDRH Publication.
11. Zhan, C., Kaczmarek, R., Loyo-Berrios, N., Sangl, J., and Bright, R.A., 2007, "Incidence and Short-Term Outcomes of Primary and Revision Hip Replacement in the United States" The Journal of Bone and Joint Surgery, 89, 526-533.
12. Baron, J.A., Barrett, J., Katz, J.N., and Liang, M.H., 1996, "Total Hip Arthroplasty: Use and Select Complications in the US Medicare Population," American Journal of Public Health, 86 (1), 70-72.
13. Peak Orthopedics & Spine PLLC., 2010, "Where does it hurt?" <http://www.peakorthopedics.com/content /where-does-it-hurt> Accessed November 17, 2010.
14. FDA, 2009, Product Code Classification Database, <http://www.fda.gov/MedicalDevices/Device RegulationandGuidance/Overview/ClassifyYourDevice/ucm051637.htm> Accessed June 28, 2010.
15. Merrill, C., and Elixhauser, A., 2007, "Hospital stays involving musculoskeletal procedures, 1997-2005," Healthcare Cost and Utilization Project, Agency for Healthcare Research and Quality (AHRQ), 1-9.